1. Physical processes in liquid and gas streams and gasdynamic and electric-discharge lasers.

2. Questions of applied mechanicsand technical physics in the problem of controlled thermonuclear synthesis.

3. Electric discharge in continuous media.

4. Combustion and explosion, shock waves, equations of state of continuous media.

5. Mechanics of superhigh parameters (the state and motion of matter at superhigh pressures, velocities, and temperatures, the interaction of powerful radiation pulses with matter, etc.).

6. Hydroaeromechanics.

7. Filtration theory.

8. Thermophysics.

9. Mechanics of a deformable solid.

10. Diagnostic methods in studies of physicochemical and gasdynamic processes.

EFFECT OF RATE OF REPLACEMENT OF WORKING GAS ON CHARACTERISTICS OF A CO_2 LASER WITH A CLOSED CYCLE

S. S. Vorontsov, A. I. Ivanchenko,
R. I. Soloukhin, and A. A. Shepelenko

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In the development of continuously operating powerful CO_2 lasers having a self-maintained glow discharge and convective cooling of the working mixture the main problem is the obtainment of uniform glow discharges in large gas volumes moving with high velocities: In such discharge instabilities develop which lead to a transition to a mode of arc-like burning in a narrow filament – contraction. In connection with the thermal limitation (destruction of the inversion upon heating of the working medium), to increase the output power of CO_2 lasers it is necessary to proportionally increase the flow rate of the working mixture through the discharge zone, which (in turn) raises the necessity of repeatedly using the same gas. This is realized in lasers with a closed cycle of gas flow [1].

Work with a closed cycle considerably complicates the obtainment of a volumetric glow discharge. It is noted that under the conditions of a closed cycle instabilities in the plasma of a glow discharge develop at lower pressures and velocities of the gas stream and at lower levels of the specific energy input [the electric power applied per unit mass of the gas stream in W/(g/sec)] than in work in an open cycle, i.e., when the gas is ejected into the atmosphere after a single use [1]. This produces changes in the chemical composition of the working gas due to chemical reactions in the plasma of the gas discharge [1-3] and the appearance of impurities from structural elements [1]. The necessity arises of continuously restoring the composition of the working mixture in the working circuit through partial evacuation and the admission of fresh gas. In this case it is obvious that the higher the rate of gas replacement, the better the original composition of the mixture is restored. At present not only is there an absence of reports in which the effect of the rate of gas renewal on the laser characteristics is analyzed, but also in the majority of publications no information is provided on the choice of the rate of replacement of the working gas.

The present report is devoted to a study of the effect of the rate of gas renewal on the characteristics of a closed-cycle CO_2 laser. We will characterize this rate by the ratio of the flow rate of gas continuously re-

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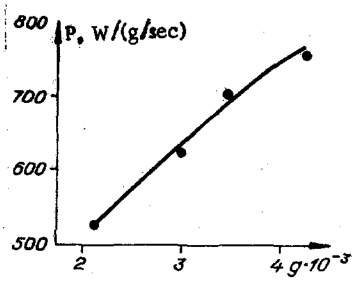

Fig. 1

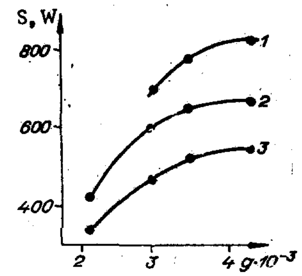

Fig. 2

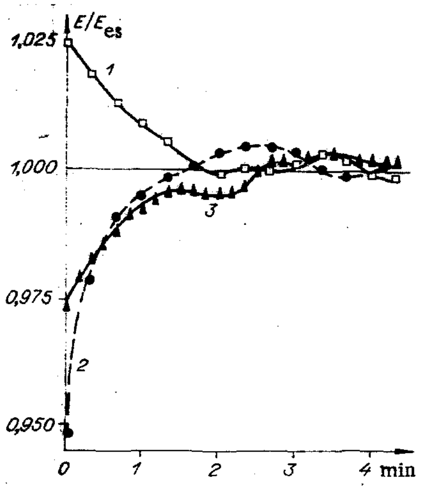

Fig. 3

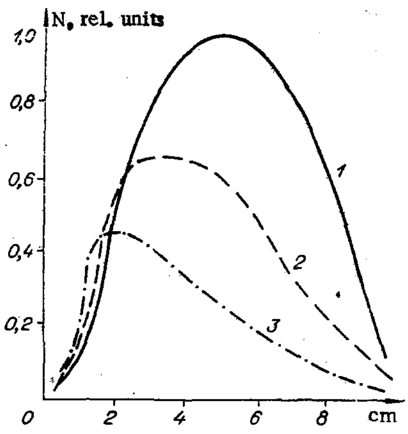

Fig. 4

moved from the laser with the constant inflow of fresh mixture to the flow rate of the working gas continuously circulating through the zone of the electric discharge: $g = G_1/G$. First of all, we study the effect of the rate of renewal on the limiting value of the specific energy input which can be stably achieved without a transition of the discharge from the glow to the arc mode, as well as on the value of the output optical power at constant levels of energy input. The experiments were conducted on the laser described in [4] with a gas stream velocity of 35 m/sec, a pressure of 16 mm Hg, and a composition of the admitted gas of $p_{CO_2} : p_{N_2} : p_{He} = 1:3:4$, which corresponds to a gas flow rate of 30 g/sec in the working section. In this laser the discharge is stabilized between two parallel electrodes (copper tubes) with a length of 1 m and a distance of 8 cm between them. The results are presented in Figs. 1 and 2.

The dependence of the limiting specific energy input P on the parameter g is presented in Fig. 1. Beginning with values of $g \leqslant 5 \cdot 10^{-3}$, with a decrease in the flow rate of the replaced gas the limiting attainable input of electrical energy declines rapidly (by 1.5 times with a twofold decrease in g from 0.4 to 0.2%). The dependence of the output optical power S on the fraction of replaced gas is shown in Fig. 2 for different energy inputs [curve 1: 600; 2: 500; 3: 400 W/(g/sec)]. The output power also declines sharply with a decrease in the flow rate of the replaced gas. At high enough rates of replacement the curves emerge into a steady state, i.e., for this dependence there is an "optimum rate" of replacement of $\simeq 0.5\%$. At low rates of renewal of the working gas the experiments were complicated by the rapid "contamination" of the electrode surfaces, the rate of which grew with a decrease in the fraction of gas renewal, which led to an increase in the probability of random transitions of the glow discharge into an arc; this occurred at all levels of applied power, even very low levels.

The reason for the decrease in the limiting attainable level of energy input with a decrease in the rate of gas renewal is evidently an increase in the concentrations of electronegative impurities, which affect the kinetics of the production and loss of charged particles in the gas discharge [2, 3]. The effect of the replacement rate on the generation efficiency is probably due to a change in the CO_2 concentration [1, 2] and a change in the average energy and distribution function of the electrons which determine the rate of populating of the laser levels [5, 6]. A chemical analysis of the gas mixture by the absorption method showed that with a replacement of 0.3% and an energy input of 500 W/(g/sec) a chemical composition is established in which the partial CO fraction is about 3%, while the CO_2 concentration is only two thirds of the initial concentration at admission.

Measurements of the electric field strength, made by the method of a twin electrical probe, showed that upon abrupt changes in the mode of operation of the discharge (rapid changes in the magnitude of the current) one observes transitional changes in the field which have an exponential character in time.

Data on the variation of the electric field strength E, normalized to its steady value E_{es} established by the end of the transition process, are presented in Fig. 3 as a function of time (the characteristic time of replacement of the working gas is 65 sec). Graphs are presented for a discharge with a steady current of 1 A and a gas velocity of 35 m/sec with a CO_2 pressure of 2 mm Hg in the system; curve 1: preceding current of 2 A; 2: 0.5 A; 3: 0. It is interesting that the measurements of the characteristic times of such processes led to values roughly coinciding with the characteristic time of renewal of the gas mixture in the laser, which can be defined as the ratio of the total volume V of gas in the laser to the volumetric evacuation rate G_1 ($\tau = V/G_1$).

In connection with the strong effect of the rate of replacement of the working gas on the power of the output laser beam which was discovered it is important to establish the nature of the variation in the level of inversion in the discharge zone. The field of spontaneous IR emission of CO_2 from the upper laser level at the wavelength $\lambda = 4.3\ \mu$ (Fig. 4) was measured by the method presented in [7]. Relative measurements of the intensity of a cross section give an idea of the spatial distribution of the population of the upper laser level. Three oscillograms taken in one cross section of the discharge at a distance of 3 cm from the anode are presented in Fig. 4 (1: $g = 3.5 \cdot 10^{-3}$; 2: $g = 3 \cdot 10^{-3}$; 3: $g = 2.3 \cdot 10^{-3}$). The relative population of the upper laser level is plotted as a function of the distance down the gas stream to the plane of the electrodes. The different oscillograms correspond to different values of the parameter g(%). It is seen that with a decrease in the rate of replacement the population maximum decreases and shifts upstream. In all cases the characteristic size of the relaxation zone remains constant while the region where the electrical excitation of molecules takes place narrows and is localized near the plane of the electrodes. Such behavior of the spatial distribution of the population of the upper laser level must evidently be explained by a contraction of the characteristic length of the discharge zone in the direction of the stream, which may be connected with an increase in the rate of loss of charged particles owing to electron capture by electronegative impurities, the concentration of which increases with a decrease in the degree of replacement of the gas.

Thus, the experimental results presented above clearly show that the energetic and optical characteristics of CO_2 lasers having closed cycles are sensitive to the rate of renewal of the working gas. Beginning with a certain "threshold" value a decrease in the rate of renewal leads to a sharp decline in the limiting power which can be applied to the discharge, as well as to worsening of the optical characteristics of the medium, which is manifested primarily in a decrease in the efficiency of the system (at any level of applied electrical power). This fact must be allowed for when determining the main working characteristics of convective lasers with closed cycles, with the "threshold" value of g evidently depending strongly on the specific construction of the pump-through system and the electrode system, on the dimensions of the discharge zone, etc. In conclusion, we note that the absence of data on the rate of renewal in the publications of various authors devoted to research in the mode of a closed cycle leads to definite difficulties in the analysis and comparison of the results of these studies.

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